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INVESTIGATION OF MECHANICAL PARAMETERS IN HOT ROLLING

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ABSTRACT

Investigation of the hot rolling behavior of ingots of a Ti-based alloy with additiona of Al, V, Mo, and Zr. Tselikov's equation is used to determine the friction coefficients from the mean values of the specific pressure. Toughness and tensile strength were determined for various temperatures, rolling rates, and degrees of deformation. The optimum rolling temperature is given as 800 to 1000°C.

In the present article the author describes the investigation /91* of technological properties of a Ti-based alloy with additions of Al, V, Mo, and Zr, which has been developed by the Russian industry. The purpose of this investigation was to determine the optimal temperatures and mechanical parameters for the pressure treatment of the alloy brought to a high temperature. This alloy has the (α + B) - phase structure. It can be hardened thermally, may be readily welded in the atmosphere of argon, and possesses quite satisfactory stamping capability. At 500°C the alloy sheets have the limit strength of about 70 kG/mm^2 and a relative elongation of 24-26%.

Bars of the alloy, obtained in a vacuum electric arc oven with a separable electrode, served as a starting material. The hot bars, 120 mm in diameter, were forged by a 150 kg hammer into rods having the square cross-section of 40x40 mm, and these in turn were forged by a 75 kg hammer into rods with the diameters 14 and 25 mm, and into plane blanks of 12-20 mm thickness.

To remove the internal stresses, generated in the forging process, the bars and flat blanks were annealed in an electric furnace in the usual atmosphere at a temperature of 800°C for two hours. Upon annealing, the blanks were cooled in a pile in the air.

In order to perform static tests on stretching, the annealed rods were machined into circular gagger specimens with a diameter of the working part equal to 8 mm and a computational length of 40 mm.

The stretching of the specimens at room temperature took place in a 40-ton press, and at elevated temperatures in a tensile testing machine of the type R-5.

* Note: Numbers in the margin indicate pagination in the original foreign text.

When heated to a temperature above 800°C, the specimens were maintained at a specified temperature for 10-15 minutes; when heated to temperatures below 700°C, the holding time was increased to 25 minutes.

The curves represented in Figure 1 were plotted on the basis /92 of the results of static tests on stretching at different temperatures.

In order to perform clinching tests, the forged and annealed rods 25 mm in diameter were machined into cylindrical samples 20 mm in diameter and 30 mm high.

The tests determining the maximal degree of deformation before the appearance of the first crack were conducted with a vertical drop hammer with a falling ram. The weight of the falling parts of the drop hammer was 194 kg. The height, above the level of the lower block, to which the ram was lifted was equal to 2.1 m.

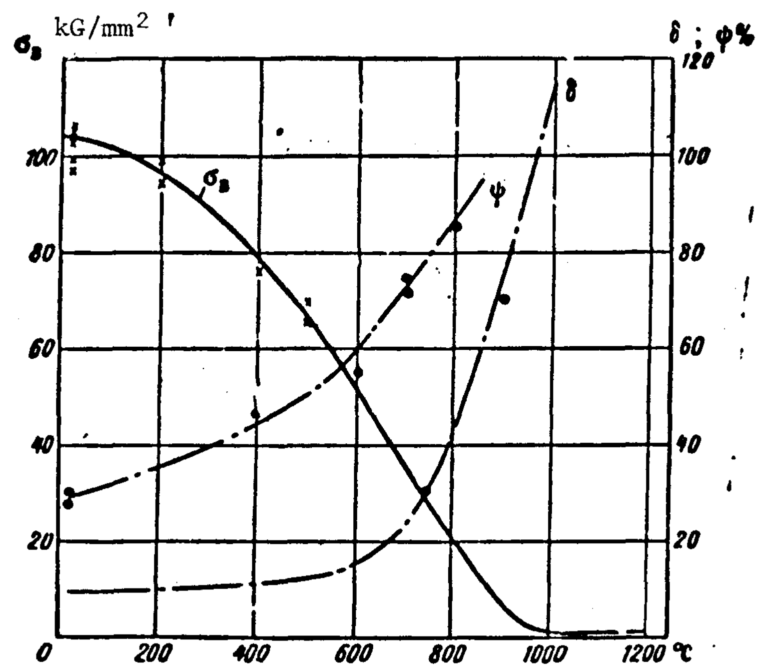

Figure 1

The Dependence of Mechanical Properties of the Alloy on Temperature in Static Stretching

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The samples were clinched every 100°C, starting with room temperature and going up to 1100°C.

To decrease the cooling influence of the drop hammer blocks, the latter were heated before each series of tests by steel blanks heated to 500-600°C and fastened between the blocks.

The amount of sample deformation was set by placing rings on the lower block of the drop hammer which limited the movement of the upper block.

The thicknesses of the constraining rings were chosen in such a was that, by combining them, it was possible to obtain any degree of deformation within an accuracy of 1%.

The graph showing the change in the degree of deformation up to the appearance of the first crack as a function of the temperature is given in Figure 2. /93

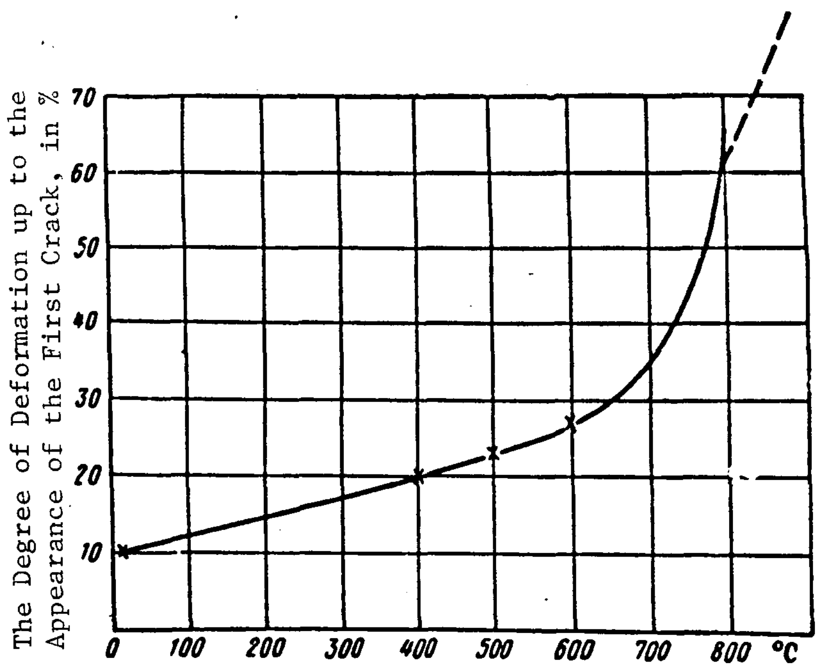

Figure 2

Temperature Dependence of the Maximal Degree of Deformation up to the Appearance of the First Crack

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Tests for the impact strength were conducted in an Amsler's pendulum impact machine with a maximal impact energy of 30 kGm.

The specimens were machined from forged and annealed rods. The dimensions of the Menagé-type specimens were standard: the square cross-section was 10 x 10 mm.

The specimens were tested every 100°C, starting with room temperature and continuing up to 1000°C.

The specimens were heated in a muffle electric furnace. In order to achieve minimal heat losses during the transfer of the specimens from the furnace to the impact machine, the samples were wrapped up before loading into the furnace with an asbestos cord 2 mm in thickness. By means of comparative tests at room temperature between specimens wrapped up in the asbestos cord, and ordinary specimens, it was found that the difference in the results obtained was negligible.

The curve showing the impact strength a_m as a function of the temperature at which the test was performed is represented in Figure 3.

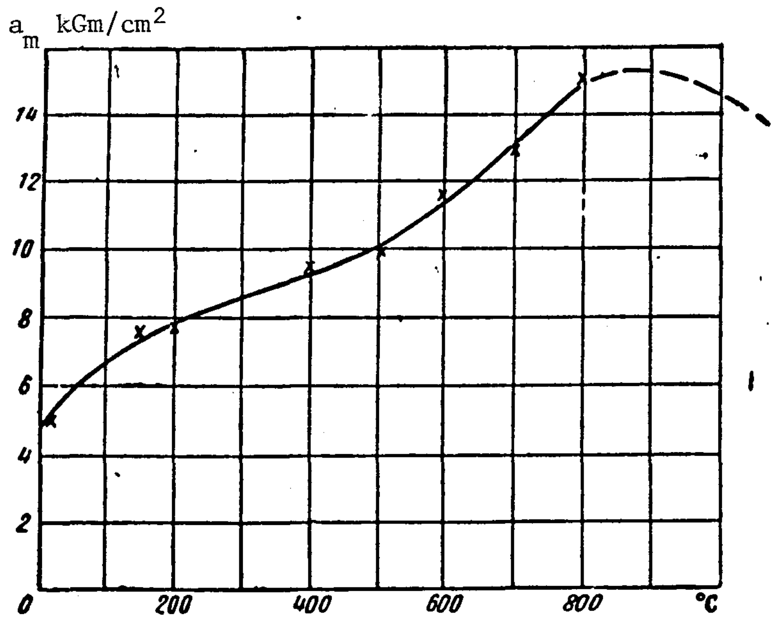

Figure 3

Dependence of the Impact Strength on the Temperature

From an inspection of the curves given in Figures 1, 2, and 3, it follows that with the increase in temperature, starting with 750-850°C, the relative narrowing of the neck, the maximal degree of deformation up to the appearance of the first crack, and the impact strength increase considerably.

In order to check the ductility of the alloy at elevated temperatures, wedge-shaped samples were rolled using the method of A. I. Chepizhenko (Ref. 1). /94

The wedge-shaped samples for rolling were prepared from forged and annealed rods. The dimensions of the wedge-shaped samples were chosen to be the following: length - 200 mm; width - 30 mm; upper height - 25 mm; lower height - 5 mm.

On the inclined wide surface of the sample, marks were drawn every 20 mm.

Before the rolling, the samples, which were measured in advance, were heated in an electric furnace. Upon reaching a specified temperature, the test was performed for 20 minutes.

The wedge-shaped samples were rolled in a two-roll mill with rolls of 334 mm in diameter, at a circular velocity 0.64 m/sec.

The rolling took place at temperatures from 500 to 1200°C, every 100°C. At each temperature three wedge-shaped samples were rolled.

Table 1 presents the results derived from rolling the wedge-shaped samples; in the graph "Maximal Deformation up to the Appearance of a Crack", the lowest values for this deformation out of all those obtained are presented.

From Table 1 it follows that within the temperature range 850-1200°C the alloy in question possesses satisfactory ductility. Considering the fact that, with an increase in temperature above 1100°C, oxidation in the air strongly increases, one has to consider 850-1100°C as the optimal temperature range for pressure treatment of the alloy in a hot state. /95

Determination of the Resistance to Deformation (Tension of Plastic Stretching) at High Temperatures, High Rates and Various Degrees of Deformation

The samples for dynamic tests on stretching were prepared analogously to those for static stretching.

A three-ton chain wire-drawing machine (Ref. 2) was used as the tensile testing machine. The carriage of the machine was rigidly connected with the moving clamp of a stretching device. /96

By changing the gears of the drive mechanism of the machine, one could set the speed of the chain at 222, 520, and 1400 mm/sec. For the computational length of a sample equal to 40 mm, the rate of deformation

TABLE 1

RESULTS DERIVED FROM ROLLING THE WEDGE-SHAPED SAMPLES OF THE ALLOY IN QUESTION AT ELEVATED TEMPERATURES

Temperature °C	Width of Sample after Rolling, mm	Maximal Reduction up to Appearance of Crack, mm	Maximal deformation up to Appearance of crack, %	Maximal Capture Angle up to Appearance of Crack, Degrees
600	19,9	5,1	20	10°10′
700	12,7	12,3	49	15°50′
800	10,8	14,2	57	16°44′
900	7,0	18,0	72	18°50′
1000	6,0	19,0	76	19°22′
1100	4,2	20,8	83	20°05′
1200	5,0	20,0	80	19°52′

TABLE 2

NUMERICAL VALUES OF RATE COEFFICIENTS AT VARIOUS TEMPERATURES, RATES, AND DEGREES OF DEFORMATION

ψ %	Temperature in °C											
	800°			900°			1000°			1100°		
	Rate of Deformation											
(1)	5,56 сек$^{-1}$	13,0 сек$^{-1}$	35 сек$^{-1}$	5,56 сек$^{-1}$	13,0 сек$^{-1}$	35,0 сек$^{-1}$	5,56 сек$^{-1}$	13,0 сек$^{-1}$	35,0 сек$^{-1}$	5,56 сек$^{-1}$	13,0 сек$^{-1}$	35,0 сек$^{-1}$
5	1,30	1,36	1,43	1,94	2,00	2,55	2,72	3,22	3,91	2,16	2,89	3,48
10	1,34	1,41	1,49	2,06	2,16	2,73	2,91	3,42	4,13	2,25	3,05	3,75
15	1,38	1,42	1,52	2,19	2,31	2,81	3,10	3,64	4,45	2,34	3,14	3,95
20	1,41	1,46	1,57	2,32	2,41	2,89	3,20	3,80	4,64	2,41	3,23	4,14
25	1,44	1,51	1,65	2,40	2,48	2,95	3,24	3,85	4,77	2,53	3,42	4,35
30	1,47	1,55	1,70	2,48	2,56	3,06	3,30	3,99	4,90	2,65	3,58	4,56
35	—	—	—	—	—	—	3,37	4,08	5,00	2,78	3,74	4,78
40	—	—	—	—	—	—	3,48	4,18	5,22	2,91	3,92	4,95

ψ - is the relative narrowing of the sample neck.

(1) - Seconds.

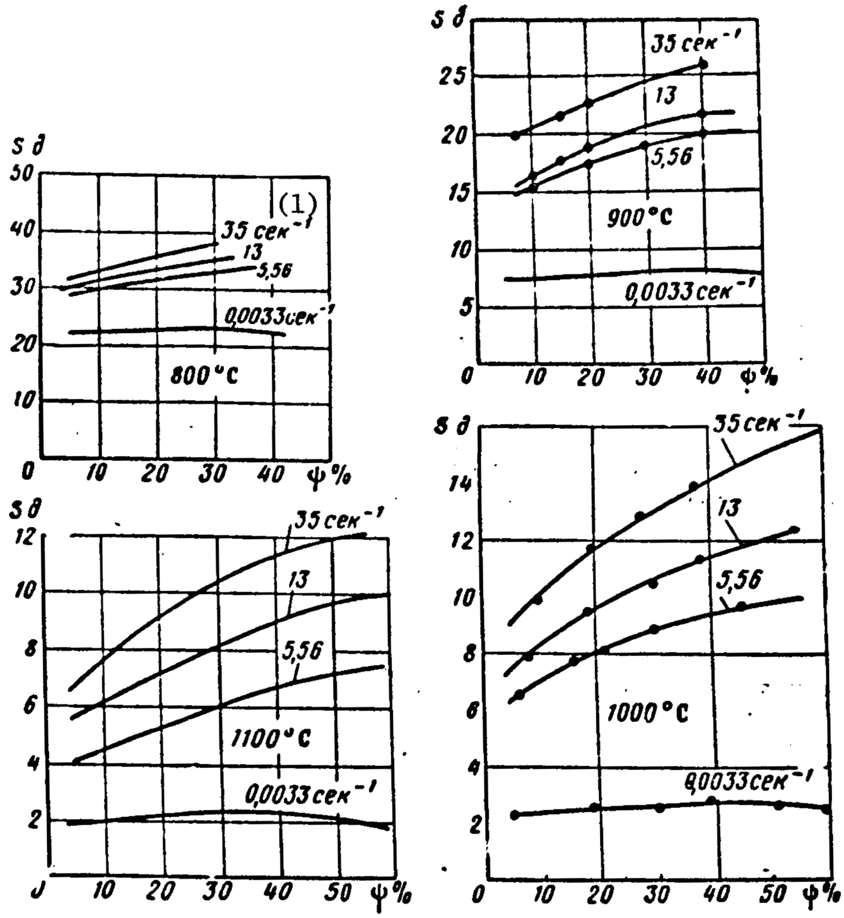

Figure 4

Dependence of the Tension in Plastic Stretching $S\partial$ on the Degree and Rate of Deformation at Various Test Temperatures

(1) - Seconds.

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was in this case 5.56, 13, and 35 sec^{-1}, respectively.

Stress, which was generated during the stretching of a sample, was measured by means of a hydraulic electric resistance dynamometer with wire feelers. In order to register the changes of the geometrical dimensions of a sample in the deformation process, a wire bridge recording the expansion, and a photoelectric device registering the lateral deformation of the sample, were provided in the stretching apparatus (Ref. 3).

The procedure for working with the indicated devices is described in (Ref. 3). /97

The samples were stretched at the temperatures 800, 900, 1000, 1100°C. The samples were heated in a tubular electric furnace with silicon carbide heating elements; these elements were used due to their greater reliability at high heating temperatures, and due to the necessity of equipping the furnace with open slits. The heating temperature was measured by means of a thermoelectric pyrometer with a platinum-rhodium thermocouple inserted into the furnace until it touched the operational part of the sample.

The curves showing the dependence of tension in plastic stretching on the rate and degree of deformation at various temperatures, which are given in Figure 4, were plotted on the basis of the results of processed experimental data. Table 2 gives the numerical values of the rate coefficients for various temperatures, rates, and degrees of deformation.

Determination of Mean Specific Pressures in Flat Rolling

Flat blanks which were planed over every surface and having dimensions of 11 x 158 x 100 mm were used for rolling. In order to eliminate the influence of the blank width on the specific pressures, the blanks were set into the rolls with their large surface down. In this case, the ratio of the width of the rolled blank to the height was above 14.

The rolling was performed on a "Duo" mill with a roll diameter of 334 mm, and a circular velocity of rotation of 0.64 m/sec. Before rolling, the rolls were heated in advance by means of specially constructed electric furnaces to a temperature on the order of 200°C.

To register the total roll pressure of the metal, hydraulic dynamometers, calibrated in advance in a 40-ton tensile testing machine for stresses up to 40 tons, were placed under the adjusting screws of the mill. Wire, electric resistance sensors, which were on the /98
hydraulic dynamometer, were assembled in a non-amplification scheme, given in (Ref. 4). This permitted the unbalance current to be recorded on the POB-14 oscillograph without any amplification.

The rolling was conducted at temperatures of 1100, 1000, 900, and 800°C. The blanks were heated in an electric furnace placed close to the mill. For each temperature, the blanks were rolled in one operation with degrees of deformation of 10, 20, 30, and 40%.

Total and mean specific roll pressures for the above described conditions were determined by processing the oscillograms obtained.

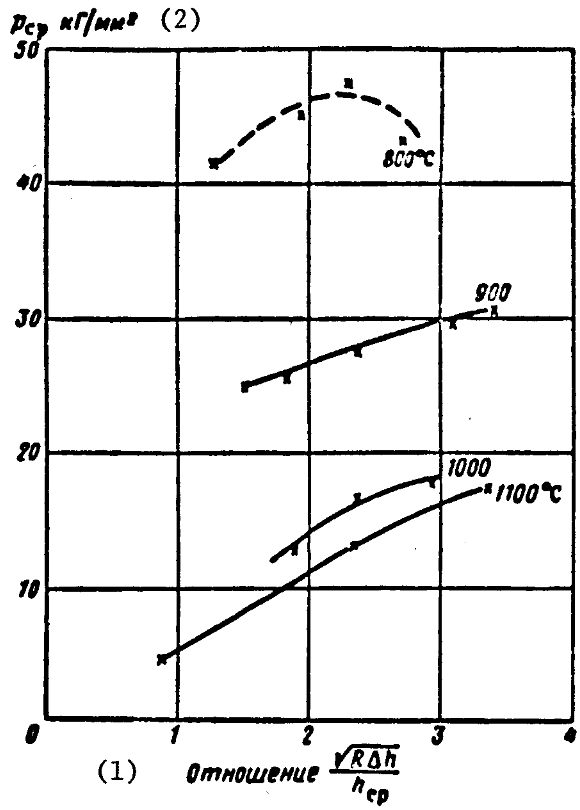

Figure 5

Mean Specific Roll Pressure as a Function of Temperature and the Ratio $\sqrt{R\Delta h}/h_{av}$

(1) - Ratio $\frac{\sqrt{R\Delta h}}{h_{av}}$ (2) - P_{av} kG/mm^2

Figure 5 shows the dependence of the mean specific roll pressure on the temperature and the ratio 1: h_{av} (length of the deformation center divided by the mean thickness of the strip).

Determination of the Friction Coefficients in Rolling

Making use of the well-known equation of A.I. Tselikov, which determines the mean specific pressures in rolling, one can determine the friction coefficients in rolling by the trial-and-error method.

The mean rate of deformation in rolling u_{av} was calculated from the formula of A.I. Tselikov (Ref. 5)

$$u_{av} = \frac{v}{l} \cdot \frac{\Delta h}{H},$$

where v is the circular velocity of the rolls;
l is the length of the capture arc;
Δ h is the absolute reduction;
H is the initial thickness of the strip.

The degree of deformation ε_{av} in one operation, over the length of the furnace, was calculated from the formula

$$\varepsilon_{av} = \frac{2}{3} \frac{\Delta h}{H}.$$

In Tselikov's formula $P_{av} = 1{,}15\, n_{\sigma} s_{\partial}$.

The coefficient of the stressed state n_{σ} can be represented as a product of three coefficients

$$n_{\sigma} = n'_{\sigma} n''_{\sigma} n'''_{\sigma},$$

where n'_{σ} is the coefficient accounting for the effect of the external friction;
n''_{σ} is the coefficient accounting for the effect of the external zones;
n'''_{σ} is the coefficient, accounting for the effect of tension, which equals in our case 1;

when $\ell/h_{av} < 1$ $n'_{\sigma} = 1$, consequently, $n_{\sigma} = n''_{\sigma} = \left(\frac{\ell}{h_{av}}\right)^{-0.4}$

when $\ell/h_{av} > 1$ $n''_{\sigma} = 1$;

$$n_{\sigma} = n'_{\sigma} = \frac{2(1-\varepsilon)}{\varepsilon(\delta-1)} \left(\frac{h_n}{h}\right)\left[\left(\frac{h_n}{h}\right)^{\delta} - 1\right],$$

where h_n/h is the ratio of the height of the rolled strip in its neutral cross-section to its final height, and $\delta = \mu \frac{2l}{\Delta h}$, where ($\mu$ is the friction coefficient which we have assigned). /99

Thus, having assigned the magnitude of μ, having determined δ and

$$\frac{h_n}{h} = \left\{\frac{1 + \sqrt{1 + (\delta^2 - 1)\left(\frac{H}{h}\right)^{\delta}}}{\delta + 1}\right\}^{1/\delta}$$

and knowing $\varepsilon = \frac{\Delta h}{H}$, we substitute the computational p_{av}. We thus determine $S\partial$ from the curves representing the dependence of tension in plastic stretching on the degree and rate of deformation at the corresponding temperature.

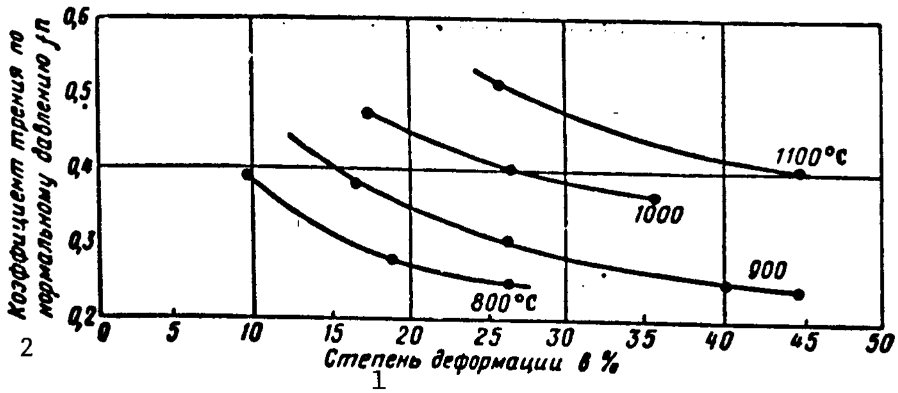

Figure 6

Dependence of the Friction Coefficient for Normal Stress on the Magnitude of Reduction and on the Rolling Temperature

(1) - Degree of deformation %; (2) - Friction coefficient for the normal pressure (stress).

The result obtained was compared with the magnitude of p_{av} determined by measurement directly from the experiments. Figure 6 shows the dependence of the friction coefficients for normal stress on the reduction and the rolling temperature. The friction coefficients assumed in plotting the curves were such that the magnitude of p_{av} determined by calculation differed from the magnitude of p_{av} obtained from experiments by between -14 to +10%.

Conclusions

1. The optimum interval for pressure treatment of the alloy in question is 800-1100°C.

2. The utilization of the curves presented in this article representing the dependence of the tension in plastic stretching (resistance to deformation) on the temperature, rate, and degree of deformation enables one to calculate the mechanical parameters in the pressure treatment of the alloy in question in a hot state.

3. The friction coefficients for normal pressure in rolling, /100
obtained by converting the experimental data according to the formula of A. I. Tselikov, are fully applicable in practical computation.

References

1. Chepizhenko, A.I. Metod issledovaniya metalla prokatkoy klinovidnykh obraztsov (The Method of Investigating Metals by the Rolling of Wedge-Shaped Samples). Zavodskaya Laboratoriya, No. 4, 1947.
2. Donstov, S.N., Berman, S.I. Tsvetnyye Metally, No. 11, 1958.
3. Kachaynik, O.I., Berman, S.I. Opredeleniye napryazheniy plasticheskogo rastyazheniya pri vysokikh temperaturakh i skorostyakh deformatsii (The Determination of Tensions in Plastic Stretching at High Temperatures and Rates of Deformation). Zavodskaya Laboratoriya, No. 8, 1962.
4. Dontsov, S.N., Berman, S.I. Izvestiya Vysshikh Uchebnykh Zavedeniy, Tsvetnaya Metallurgiya, No. 3, 1959.
5. Rolling Industry, (prokatnoye proizvodstvo). Handbook edited by Ye. S. Rokotyan, Vol. 1, Metallurgizdat, 1962.

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